

FACTORS AFFECTING THE BENDING STIFFNESS OF TEXTILE FABRICS AND METHODS OF ITS MEASUREMENT: AN ANALYTICAL REVIEW

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Abstract

Bending stiffness largely decides how a textile holds its shape and drapes, yet its measurement in practice still depends on manual, operator-controlled procedures. This paper analyses published studies on the factors that change the bending stiffness of fabrics and on the instruments used to determine it in testing laboratories. Reported laboratory data show that repeated laundering of a cellulosic fabric reduced its bending stiffness by up to 50.5 %, while the degree of polymerisation of cellulose fell by 34.3 %. Biomodification treatments were reported to soften linen garment zones several times over. A comparison of standardised cantilever-type methods reveals two persistent weaknesses: unevenly distributed pressing force and the absence of a controlled displacement speed. Proposals for a mechanised device and the growing field of smart textiles, where conductive yarns add further requirements, are also considered. The analysis supports the development of a new stiffness-measuring device with regulated pressure and speed.

Keywords: bending stiffness; textile materials; fabric; interlining; laundering; cellulose degradation; standardised testing; cantilever method; smart textiles; measuring device

Bending stiffness is the resistance that a fabric offers when external forces try to change its shape. Its reciprocal quantity, flexibility, is the property most often judged in practice: the more a fabric bends under a given load, the lower its stiffness [1]. The

indicator is of primary importance for work clothing in the construction trades, for suiting and coat fabrics, and for interlinings that give a garment its form [2].

Service conditions alter stiffness. In a study of materials for construction-industry workwear, six polyester–cotton and cotton fabrics from British, Russian and Belarusian producers were chosen, and the change of their properties during repeated laundering was followed [2], [3]. Earlier research on cellulosic textiles had shown that repeated washing lowers the degree of polymerisation of cellulose, raises its solubility in alkali and causes carboxyl groups to accumulate [4], [5]. Table 1 collects the reported figures and adds relative changes calculated by the author. After 34 one-hour washes, the mean degree of polymerisation fell from 1400 to 920 (–34.3 %), the bending stiffness fell from 3558 to 1762 relative units (–50.5 %), and the loss of strength reached 39.6 %. Across the four states in the table, stiffness and degree of polymerisation move together ($r = 0.98$), although four points can support only a descriptive statement. Outdoor exposure acts in the same direction: the strength of fabrics declines gradually under weathering, and the size of the decline depends on fibre nature, fabric parameters and finishing [6].

Table 1. Changes in a cellulosic fabric after repeated laundering

Indicator	Before washing	17 washes × 20 min	34 washes × 20 min	34 washes × 1 h
Mass loss, %	–	2.75	3.59	5.6
Strength loss, %	–	18.1	26.9	39.6
Bending stiffness (relative units)	3558	3034	2579	1762
Change in stiffness, % (calculated)	–	–14.7	–27.5	–50.5

Indicator	Before washing	17 washes × 20 min	34 washes × 20 min	34 washes × 1 h
Mean degree of polymerisation	1400	1320	1100	920
Change in polymerisation degree, % (calculated)	–	–5.7	–21.4	–34.3
Carboxyl groups, % of fabric mass	0.112	0.278	0.369	0.453

Stiffness can also be changed on purpose. Work on linen clothing defined ranges of stiffness for separate zones of women's dresses, blouses and suits, proposed optimal values for the waist and shoulder zones, and combined linen fabric with interlining in a technology of zonal biomodification, that is, local softening of selected parts and units [7]–[9]. Table 2 contrasts the liquid and low-modulus variants of the treatment. The authors observed reductions of stiffness of up to 6.4 times for soft and plastic articles, whereas for suiting and raincoat assortments the low-modulus technology was advised because the largest reduction it produces is 3.7 times [7]–[9]. A separate study of linen fabrics established the anisotropy of their bending behaviour and an analytical link between the ability to recover shape after bending and the structure of the fabric [10].

Table 2. Stiffness of garment fabrics (mN·cm²) before and after liquid and low-modulus biomodification [7]–[9]

Garment group	Initial fabric stiffness	Required stiffness of zones	Stiffness after liquid treatment	Stiffness after low-modulus treatment
Shirts	5.9–74	low 1.1–9.5; high 10.0–32.4	low 0.92–11.6; high 5.4–67.3	low 1.6–19.9; high 5.4–68.5

Garment group	Initial fabric stiffness	Required stiffness of zones	Stiffness after liquid treatment	Stiffness after low-modulus treatment
Thin trousers	15.6–158	low 1.1–13.0; high 13.5–35.1	low 2.4–24.7; high 14.2–143.6	low 4.2–42.5; high 14.5–146.3
Jackets	22.2–276	low 1.5–6.3; high 6.8–52.0	low 3.5–78.9; high 20.2–250.9	low 5.9–74.2; high 20.6–255.6

The reliability of such comparisons depends on the measuring instrument. The device specified in GOST 29104.21-91 and ASTM D1388-18 served as the prototype for laboratory equipment of this kind [11], [12]. In it the operator produces both the force and the speed, and a ruler is used to push the specimen by hand. The pressing force is therefore not distributed evenly, the displacement cannot be made at a set speed, and the accuracy of the result becomes questionable; since five specimens must be averaged to characterise one fabric, the procedure also takes a long time. Analysing the problem, Mirkhojaev noted that warp and weft linear density, areal density and fibre composition differ between fabrics, so the force applied through the ruler should differ with fabric type and be standardised [13]. The proposed remedy was an additional mechanism with a drive, a thicker ruler with sections that spread the load evenly and allow the force to be changed, and a reciprocating horizontal movement of the specimen [13]. GOST 10550-93 extends the scope to clothing fabrics, knitted and nonwoven materials, artificial fur, interlining and haberdashery, and prescribes instruments PT-1 and PT-2 [14]. Its methods are chosen by the absolute deflection f of the material, as summarised in Table 3. Specimens are cut at least 5 cm from the selvedge (at least 15 cm for artificial fur) and must be free of creases [14].

Table 3. Standardised methods for determining bending stiffness and the proposed improvement

Standard or proposal	Principle	Reported scope or limitation
GOST 29104.21-91; ASTM D1388-18 [11], [12]	Ruler-assisted cantilever test; the specimen is pushed by hand	Uneven pressing force; no set speed; five specimens averaged, hence long test time
GOST 10550-93, cantilever (contactless) method [14]	Instrument PT-1 or PT-2	Materials with absolute deflection $f \geq 10$ mm
GOST 10550-93, loop method [14]	Instrument PT-1 or PT-2	Materials with $f < 10$ mm
GOST 10550-93, variable-length method [14]	Instrument PT-1 or PT-2	Materials with $f \geq 60$ mm
Mechanised device proposed in [13]	Thicker ruler with force-regulating sections; reciprocating horizontal movement	Force set according to fabric type and standardised

The same question arises for new classes of materials. Recent reviews describe smart textile fabrics as materials combining sensors, actuators and electronic components, and report rapid progress together with unresolved challenges [15], [16]. A commonly used scheme divides them by function into temperature-regulating, shape-memory, waterproof-breathable and data-collecting fabrics, and by degree of intelligence into passive, active and very smart textiles, with five basic functions: sensing, data processing, actuation, storage and communication [16], [17]. For

conductive antistatic fabrics the literature describes a construction in which cotton, about 60 %, acts as the insulating part and a polyacrylonitrile-based conductive component, about 40 %, carries the current. The reported yarn has a specific breaking load of up to 9.0 cN/tex, an elongation of up to 14.0 %, a linear electrical resistance of up to 35 kΩ/m, a twist of 608 turns per metre and a linear density of 50 ± 2 tex, with mesh cells of 5–30 mm [18]–[19]. Because components of such different nature are combined in one structure, the bending stiffness of these fabrics is unlikely to be predicted from data on cotton alone, which increases the need for a repeatable measuring method.

Taken together, the reviewed studies show that bending stiffness changes under laundering, weathering and finishing, that it can be regulated in garment zones, and that the standardised instruments used to measure it still rely on manual loading. These findings justify the development of a device with regulated pressing force and displacement speed, which is the direction pursued in the author's own analysis of the subject.

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